Chapter 4
Surveillance of Traumatic Brain Injury

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Traumatic Brain Injury (TBI) Surveillance in Civilian Populations

Clinical Case Definitions

Clinical case definitions describe the criteria for diagnosing TBI and provide an important background for evaluating epidemiologic case definitions. Two clinical indicators, the *occurrence* of impairment of consciousness [also referred to as alteration of consciousness (AOC), including loss of consciousness (LOC)] and post-traumatic amnesia (PTA), are the indicators most commonly used to assess acute brain injury severity and thus figure prominently in TBI clinical case definitions. The Glasgow Coma Scale (GCS) is the most widely used tool for assessing impaired consciousness (Teasdale and Jennett 1974) (Table 4.1).

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*The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army, the Department of Defense, or the Centers for Disease Control and Prevention.

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Table 4.1 Glasgow Coma Scale

Type of response		Score
Eye opening	Spontaneous	4
	To speech	3
	To pain	2
	None	1
Motor	Obeys commands	6
	Localizes pain	5
	Withdrawal	4
	Abnormal flexion	3
	Extension	2
	No response	1
Verbal	Oriented	5
	Confused	4
	Inappropriate	3
	Incomprehensible	2
	No response	1
Total[a]		

Source: adapted from (Teasdale and Jennett 1974)
[a] Total is the sum of the highest score from each category (range 3–15) (maximum = 15); higher score = less severe injury

Table 4.2 Severity of brain injury stratification

Criteria	Mild/concussion	Moderate	Severe
Structural imaging	Normal[a]	Normal or abnormal	Normal or abnormal
Abbreviated injury scale (AIS) anatomical/structural injury	1–2	3	4–6
Loss of consciousness (LOC)	0–30 min	>30 min and <24 h	>24 h
Alteration of consciousness/mental state (AOC)	A moment up to 24 h	>24 h; severity based on other criteria	
Post-traumatic amnesia (PTA)	≤1 day	>1 and <7 days	>7 days
Glasgow Coma Scale (best available score in first 24 h)[b]	13–15	9–12	3–8

Source: adapted from VA/DoD (Clinical Practice Guideline 2009)
[a] Note that minor abnormalities possibly not related to the brain injury may be present on structural imaging in the absence of LOC, AOC, and PTA
[b] Some studies report the best available GCS score within the first 6 h or some other time period

PTA, also referred to as anterograde amnesia, is defined as a period of hours, weeks, days, or months after the injury when the person exhibits a loss of day-to-day memory. TBI can be categorized as mild, moderate, or severe based on the *length* of impaired consciousness, LOC, or PTA. Criteria for determining acute severity are summarized in Table 4.2. Acute injury severity is best determined at the time of the injury (VA/DoD 2009).

Another commonly used method of assessing TBI severity is the Abbreviated Injury Scale (AIS) (AAAM 1990). This measure relies on anatomic descriptors of the injury sustained and the immediate consequences such as LOC and degree of cerebral hemorrhage. The most appropriate method of scoring AIS is manual assignment of the seven-digit codes by trained coders. Trauma centers in the USA use the AIS to grade the severity of injuries in their trauma registries. Unlike physiological measures of severity such as GCS that are best performed within minutes after TBI, AIS can be assigned after the patient has been stabilized. The AIS score for the head only is used to describe the severity of TBI (see Table 4.2).

In 1995, the US Centers for Disease Control and Prevention (CDC) published *Guidelines for Surveillance of Central Nervous System Injury* (Thurman et al. 1995a), one of the first systematic

efforts to develop a standard TBI case definition. They defined TBI as craniocerebral trauma, specifically, "an occurrence of injury to the head (arising from blunt or penetrating trauma or from acceleration/deceleration forces) that is associated with any of these symptoms attributable to the injury: decreased level of consciousness, amnesia, other neurologic or neuropsychological abnormalities, skull fracture, diagnosed intracranial lesions, or death." Additional considerations in defining and diagnosing TBI based on more recent research have been summarized in Saatman et al. (2008) and Menon et al. (2010).

Because of increased recognition of concussion or mild TBI as a specific clinical entity, separate definitions have been developed to diagnose this subgroup of persons with TBI. Although the terms concussion and mild TBI have been used interchangeably, "concussion" is preferred because it refers to a specific injury event that may or may not be associated with persisting symptoms. Therefore, although both of these terms are used in the literature cited here, the term "concussion/mTBI" is used in the remainder of this chapter.

In the USA, the most widely accepted clinical criteria for concussion/mTBI are those proposed by the American College of Rehabilitation Medicine (ACRM 1993) as follows:

A traumatically induced physiological disruption of brain function, as manifested by *at least one* of the following:

- Any loss of consciousness
- Any loss of memory for events immediately before or after the accident
- Any alteration in mental state at the time of the accident (injury) (e.g., feeling dazed, disoriented, or confused); focal neurological deficit(s) that may or may not be transient

But where the severity of the injury does not exceed the following:

- Loss of consciousness of approximately 30 minutes or less
- After 30 minutes, an initial Glasgow Coma Scale score of 13–15
- Post-traumatic amnesia (PTA) not greater than 24 hours

Criteria for concussion/mTBI used by other groups include the CDC (National Center for Injury Prevention and Control 2003) and the World Health Organization (WHO) (Carroll et al. 2004) definitions. In summary, most experts agree that the common criteria for concussion/mTBI include an initial GCS score of 13–15 or only a brief LOC, brief PTA, and normal structural findings of neuroimaging studies [e.g., head computed tomography (CT)]. (VA/DoD 2009) (Table 4.2).

Case Definitions for Administrative Data Systems

The standard TBI case definition developed by the CDC is among the most widely used for surveillance in which cases are identified using International Classification of Diseases (ICD) diagnosis codes (Marr and Coronado 2004) (Table 4.3). This definition has some limitations. First, although included in the definition as an indicator of TBI, skull fracture by itself is not necessarily a brain injury per se.[1] Second, to avoid underestimating TBIs, the code 959.01, "head injury, unspecified," is included because its introduction to ICD-9-CM (Department of Health

[1] However, a strong relationship between cranial and intracranial injury has long been recognized, with skull fracture taken as an indicator that the brain has been exposed to injurious forces. For that reason, the term "craniocerebral trauma" is still retained as a synonym for TBI (Thurman et al. 1995a; Ropper and Samuels 2009). It should be noted also that current accepted indications for radiologic imaging studies of head trauma patients are directed principally to those who already meet clinical criteria for TBI or concussion/mTBI (Jagoda et al. 2008). Therefore, the likelihood of diagnosing skull fractures in the absence of clinical TBI or mTBI appears low and probably of small effect in epidemiologic estimates of TBI incidence in general populations.

Table 4.3 CDC TBI case definition for use with data systems

TBI morbidity (ICD-9-CM codes)	
800.0–801.9	Fracture of the vault or base of the skull
803.0–804.9	Other and unqualified and multiple fractures of the skull
850.0–854.1	Intracranial injury, including concussion, contusion, laceration, and hemorrhage
950.1–950.2	Injury to the optic chiasm, optic pathways, and visual cortex
959.01	Head injury, unspecified (beginning 10/1/97)
995.55	Shaken infant syndrome
TBI mortality (ICD-10 codes)	
S01.0–S01.9	Open wound of the head
S02.0, S02.1, S02.3, S02.7–S02.9	Fracture of skull and facial bones
S04.0	Injury to optic nerve and pathways
S06.0–S06.9	Intracranial injury
S07.0, S07.1, S07.8, S07.9	Crushing injury of head
S09.7–S09.9	Other and unspecified injuries of head
T01.0	Open wounds involving head with neck
T02.0	Fractures involving head with neck
T04.0	Crushing injuries involving head with neck
T06.0	Injuries of brain and cranial nerve with injuries of nerves and spinal cord at neck level
T90.1, T90.2, T90.4, T90.5, T90.8, T90.9	Sequelae of injuries of head
	Note: according to the CDC, these codes should be considered provisional until sensitivity and predictive value are evaluated

Source: (Marr and Coronado 2004)

and Human Services 1989) in the 1997 annual update resulted in a rise in its use and a corresponding drop in the use of the code 854, "intracranial injury of other and unspecified nature" (Faul et al. 2010). Some of the cases included using this definition may be head injuries (e.g., injuries to the scalp), but not brain injuries, and thus may not meet the clinical criteria for TBI. In the USA, ICD-10 codes (WHO 2007) are used for identifying TBI-related deaths, and ICD-9-CM codes (Department of Health and Human Services 1989) for hospitalizations, emergency department (ED) visits, and outpatient visits, until such time as ICD-10-CM is implemented. In anticipation of the change to ICD-10-CM, the CDC has also released a proposed surveillance case definition using the new codes (Table 4.4).

In an effort to facilitate surveillance of concussion/mTBIs, the CDC developed a proposed ICD-9-CM code-based definition for mild TBI designed to be used with data for persons treated in health-care facilities (National Center for Injury Prevention and Control 2003) (Table 4.5). Bazarian et al. (2006) conducted a prospective cohort study of patients presenting to an ED and compared real-time clinical assessment of mild TBI with the ICD-9-CM codes for this definition assigned after ED or hospital discharge. They found that the sensitivity and specificity of these codes for identifying concussion/mTBIs were 45.9 and 97.8%, respectively, suggesting that estimates based on these codes should be interpreted with caution.

Of note, CDC periodically updates the TBI surveillance case definitions; thus, a more recent version may be in use.

Administrative Data Sources

Quantitative data for population-based assessment of injuries, including TBI, are available from several sources in most high-income countries, including the USA. Many of the data sets that are easy to obtain were designed for other administrative purposes, for example, hospital billing, and thus

Table 4.4 Proposed CDC ICD-10-CM case definition for traumatic brain injury

S01.0	Open wound of scalp	S07.0	Crushing injury of face
S01.1	Open would of eyelid and periocular area[a]	S07.1	Crushing injury of skull
		S07.8	Crushing injury of other parts of head[a]
S01.2	Open wound of nose[a]	S07.9	Crushing injury of head, part unspecified[a]
S01.3	Open wound of ear[a]		
S01.4	Open wound of cheek and temporomandibular area[a]	S09.7	Multiple injuries of head
		S09.8	Other specified injuries of head
S01.5	Open wound of lip and oral cavity[a]	S09.9	Unspecified injury of head
S01.7	Multiple open wounds of head		
S01.8	Open wound of other parts of head	T01.0	Open wounds involving head with neck
S01.9	Open wound of head, part unspecified	T02.0	Fractures involving head with neck[a]
		T04.0	Crushing injuries involving head with neck[a]
S02.0	Fracture of vault of skull	T06.0	Injuries of brain and cranial nerves with injuries of nerves and spinal cord at neck level
S02.1	Fracture of base of skull		
S02.3	Fracture of orbital floor[a]		
S02.7	Multiple fractures involving skull and facial bones	T90.1	Sequelae of open wound of head
S02.8	Fracture of other skull and facial bones	T90.2	Sequelae of fracture of skull and facial bones
S02.9	Fracture of skull and facial bones, part unspecified	T90.4	Sequelae of injury of eye and orbit[a]
		T90.5	Sequelae of intracranial injury
S04.0	Injury of optic nerves and pathways	T90.8	Sequelae of other specified injuries of head
		T90.9	Sequelae of unspecified injury of head
S06.0	Concussion		
S06.1	Traumatic cerebral edema		
S06.2	Diffuse brain injury		
S06.3	Focal brain injury		
S06.4	Epidural hemorrhage (traumatic extradural hemorrhage)		
S06.5	Traumatic subdural hemorrhage		
S06.6	Traumatic subarachnoid hemorrhage		
S06.7	Intracranial injury with prolonged coma		
S06.8	Other intracranial injuries		
S06.9	Intracranial injury, unspecified		

Source: (Marr and Coronado 2004)

[a]The CDC recommends including these codes on a provisional basis until sensitivity and positive predictive value are evaluated

Table 4.5 Administrative concussion/mTBI data definition for surveillance or research (ICD-9-CM)

ICD-9-CM first four digits	ICD-9-CM fifth digit
800.0, 800.5, 801.0, 801.5, 803.0, 803.5, 804.0, 804.5, 850.0, 850.1, 850.5 or 850.9	0, 1, 2, 6, 9, or missing
854.0	0, 1, 2, 6, 9, or missing
959.0[a]	1

Source: (National Center for Injury Prevention and Control 2003)

[a]The current inclusion of code 959.01 (i.e., head injury, unspecified) in this definition is provisional. Although a recent clarification in the definition of this code is intended to exclude concussions, there is evidence that nosologists have been using it to code TBIs. Accordingly, this code may be removed from the recommended definition of mild TBI when there is evidence that in common practice, nosologists no longer assign this code for TBI

have limited information concerning the causes and clinical characteristics of TBI cases. Sometimes linkage with other data sources, for example, with data abstracted separately from medical records, can be used to enhance the information they contain. Because they are among the most useful for epidemiologic research, population-based data sources are the primary focus of this section. Unless otherwise specified, TBI cases are identified from these data sources using ICD codes.

Mortality

In the USA, *National Vital Statistics System (NVSS)* mortality data [also referred to as *Multiple Cause of Death Data (MCDD)*] consist of death certificate data from all US states and territories and are collected by the National Center for Health Statistics (NCHS) (NCHS 2011). Similar mortality data are collected in other high-income and most middle- and low-income countries based on death certificates that are generally consistent with the WHO standards (WHO 1979). The compiled data are coded according to the International Classification of Diseases (WHO 2011). Because TBI, if present on the death certificate, is listed in Part I in the sequence of conditions leading to death and not as the underlying cause (which is always the external cause code, or E code), deaths involving TBI are most accurately reported as TBI-*related* deaths. An important limitation in using MCDD to identify TBI-related deaths is the fact that the conditions listed in the sequence leading to death, such as TBI, are manually coded from the death certificates. The reliability of these codes is therefore dependent upon the accuracy and completeness of the information listed, which may vary depending on who completes the certificate. In the USA, death certificates can be completed either by coroners (publicly elected officials) or medical examiners (forensic pathologists). Death certificates completed by medical examiners have a high level of accuracy (Hanzlick and Combs 1998). An example of a study that used NVSS data is Adekoya et al. (2002) in which trends in TBI-related death rates in the USA were reported.

Morbidity

Hospital Discharge Data

The National Hospital Discharge Survey (NHDS), another annual survey conducted by NCHS (NCHS 2011), includes patient discharges from a nationally representative sample of nonfederal hospitals. The NHDS provides information on principal discharge diagnosis and up to six secondary diagnoses, demographics, length of stay, and payer information. In 2010, additional secondary discharge diagnoses were added, allowing for up to fourteen. For complete ascertainment of TBI cases, it is important to search for the diagnosis in both the primary and secondary diagnosis fields. Beginning in 2011, the NHDS will be incorporated into the National Hospital Care Survey which will include all Uniform Billing form (UB-04) data on inpatient discharges from sampled hospitals. Examples of the use of NHDS data are two CDC reports (Langlois et al. 2004; Faul et al. 2010) in which NHDS data were combined with mortality and ED data to calculate estimates of the incidence of TBI in the USA.

The Nationwide Inpatient Sample (*NIS*) of the Healthcare Cost and Utilization Project (H-CUP) sponsored by the Agency for Healthcare Research and Quality (AHRQ) is a nationally representative cluster sample of discharges from nonfederal, short-term general and other specialty hospitals, excluding hospital units of institutions (AHRQ 2011a). When compared with TBI hospitalization rates for the USA calculated using the NHDS, the rates calculated using the NIS tend to be somewhat lower. The NIS data set was used to calculate TBI-related hospital admission rates in an AHRQ report (Russo and Steiner 2007).

State-based hospital discharge data (*HDD*) are available in some states that create hospital discharge data sets from their hospital care claims data. These standardized data are coded according to the Uniform Billing form (UB-92) promulgated in 1992 by the US Health Care Financing Administration [now the Center for Medicare and Medicaid Services (CMS)]. The Uniform Billing form has been updated to UB-04 as of 2007 (CMS 2010). Among states that require all hospitals within their jurisdiction to report these data, HDD sets can be used to calculate reliable estimates of the number of TBI-related hospitalizations. Using state HDD collected as part of CDC's statewide TBI surveillance initiative, some reports have presented individual state data (Hubbard 2010) or combined data from several states (Eisele et al. 2006; Langlois et al. 2003). State-based HDD for many states are also represented in the HCUP State Inpatient Databases (SID) (AHRQ 2011b). According to the AHRQ, combined SID data for all available states encompass about 90% of all US community hospital discharges. SID data have been used to compare TBI hospitalization rates across states with differing helmet laws (Weiss et al. 2010; Coben et al. 2007).

Emergency Department Data

The *National Hospital Ambulatory Medical Care Survey (NHAMCS)*, also from NCHS, includes a sample of visits to a nationally representative sample of emergency and outpatient departments of nonfederal, noninstitutional (e.g., excluding prison hospitals) general and short-stay hospitals (NCHS 2011). Beginning in 2013, NHAMCS will be incorporated into the National Hospital Care Survey. This new survey will have the potential to link emergency and outpatient department visits with hospital discharge data. Schootman and Fuortes (2000) used NHAMCS data in their study of ambulatory care for TBI in the USA. Some states maintain and analyze their own aggregate statewide ED visit data sets, for example, South Carolina (Saunders et al. 2009).

The *National Electronic Injury Surveillance System-All Injury Program* (NEISS-AIP) is an expansion of the Consumer Product Safety Commission's (CPSC) National Electronic Injury Surveillance System (NEISS) used to monitor consumer-product-related injuries (CDC 2001). NEISS-AIP includes nonfatal injuries and poisonings treated in US hospital EDs, including those that are not associated with consumer products. The NEISS-AIP uses a subsample of the EDs included in NEISS for its data collection. The NEISS-AIP coding system does not use ICD codes but rather has a fixed number of categories relevant to consumer-product-related injuries for the primary part of the body affected and for the principal diagnosis. Some limitations in TBI case ascertainment using NEISS have been reported (Xiang et al. 2007). Bakhos et al. (2010) used NEISS and NEISS-AIP data to study ED visits for concussion in young child athletes, and the CDC (2007) used NEISS-AIP to investigate nonfatal TBIs from sports and recreation activities in the US population.

Ambulatory Medical Care

The NCHS Ambulatory Medical Care Survey (*NAMCS*), another annual survey, provides information on ambulatory medical care provided by nonfederally employed office-based physicians (NCHS 2011). It is based on a sample of visits to a national probability sample of office-based physicians. According to the 2007 survey estimate, there were 106.5 million office visits due to injury (Hsiao et al. 2010). The data includes 24 items with up to three ICD-9-CM diagnoses and offer the opportunity to estimate the proportion of TBIs treated in an outpatient setting. Schootman and Fuortes (2000) included NAMCS data in their study of rates of TBI-related ambulatory care in the USA.

Data from statewide trauma registries can also be used to study serious injury, but they vary considerably in composition and content (Mann et al. 2006) and typically are not representative. The National Trauma Databank (NTDB) represents the largest aggregation of US trauma registry data, and the data from the research data sets (RDS) can be used for studies that do not require population-based estimates (American College of Surgeons 2011a). Data from more recent years are more complete due to the implementation of the NTDB National Trauma Data Standard beginning in 2007.

The NTDB National Sample Program (*NSP*) is a national probability sample of data from Level I and II trauma centers selected from the NTDB (American College of Surgeons 2011b). It was developed to overcome limitations in the ability to draw inferences about the incidence and outcomes of injured patients at the national level inherent in the NTDB because of biases associated with voluntary reporting (Goble et al. 2009). Thus, the NSP can be used to provide nationally representative baseline estimates of trauma care for clinical outcomes research and injury surveillance. The NSP data were used by the National Highway Traffic Safety Administration to investigate the incidence rates of incapacitating injuries including TBI among children in motor vehicle traffic crashes (National Highway Traffic Safety Administration 2010).

Motor-Vehicle-Related Fatalities

The Fatality Analysis Reporting System (*FARS*) contains data on all vehicle crashes that occur on a public roadway and involve a fatality within 30 days after the crash (National Highway Traffic Safety Administration 2011) and is an important source of information on TBI-related deaths associated with this cause. Beginning in 1988, the General Estimates System (GES) was added to FARS. GES is a nationally representative sample of police-reported motor vehicle crashes of all types, from minor to fatal, which allows estimation of nonfatal, crash-related TBIs in the USA. FARS has been used to investigate the proportion of bicyclist fatalities for which head injury was a contributing factor (Nicaj et al. 2009).

Sports

Because they are not routinely coded in the administrative data sets used for surveillance, sports and recreation activities are frequently underestimated as a cause of TBI, especially concussion/mTBI. For this reason, there has been increased interest in using other sports-related injury data collection systems for injury surveillance. Two examples are the NCAA Injury Surveillance System (ISS), a free internet-based athletic training record that allows monitoring of college level athletic participation, injuries, and treatments for all NCAA varsity sports (Dick et al. 2007; Hootman et al. 2007), and High School RIO™, the Internet-based data collection tool used in the National High School Sports-Related Injury Surveillance Study, a surveillance study of injuries in a national sample of US high school athletes (Center for Injury Research and Policy 2011). Examples of studies using these data sets are Gessel et al. (2007) and Frommer et al. (2011). Rates of TBI resulting from sports activities have also been derived from NEISS-AIP (Thurman et al. 1998; CDC 2007).

Use of Administrative Data Sets in Other Countries

Most of the previous examples illustrating the use of administrative data sources to assess TBI occurrence in populations are drawn from the USA. However, it should be noted that comparable resources exist and have been used to describe the epidemiology of TBI in other high-income (Hyder et al. 2007; Tagliaferri et al. 2006) and some middle- and low-income countries (Hyder et al. 2007; Puvanachandra and Hyder 2009). Indeed, among countries with universal health-care systems with public insurance, medical records may be linked across all medical care venues—hospital, ED, and even outpatient sites. This may facilitate more comprehensive assessments of the spectrum of mild, moderate, and severe TBI occurrence (Colantonio et al. 2010). Linking such records for individual patients also enables the correction of duplicate reports that can arise when patients are treated at more than one site or at different times for the same injury. The WHO Collaborating Centres for Injuries have provided general guidelines for conducting TBI surveillance in high-income as well as middle- and low-income countries (Thurman et al. 1995b).

Quality of Data Sources

The incompleteness of some important data elements is a major problem in hospital discharge and ED data systems and trauma registries. This is in part due to limitations in the quality of clinical information that health-care providers record in the medical record, which adversely affect the accuracy of ICD coding. Glasgow Coma Scale scores, for example, may not be recorded in as many as 40% of the hospital medical records of patients with TBI (Thurman et al. 2006).

Alcohol use among TBI patients can complicate diagnosis in the ED by depressing the level of consciousness, resulting in inaccuracy in the initial assessment of TBI severity. In one study, this effect reportedly was independent of the severity of the injury (Jagger et al. 1984). Findings from more recent studies, however, suggested that alcohol intoxication generally did not result in a clinically relevant reduction in GCS in trauma patients with TBI (Stuke et al. 2007) except in those with the most severe injuries (Sperry et al. 2006) and those with very high blood alcohol levels (200 mg/dl or higher) who also had intracranial abnormalities detected on CT scan (Lange et al. 2010). Inaccurate assessment of individuals with TBI, especially concussion/mTBI, in the ED can contribute to missed diagnoses (Powell et al. 2008) and underestimates of the incidence of medically treated TBI.

Because most administrative data sets do not include measures of TBI severity such as the GCS, ICD code–based injury severity measures are often applied to these data sets. Examples are ICDMAP-90 software, which assigns Abbreviated Injury Scale 1990 (AIS) scores of the head based on TBI-related ICD-9-CM codes (MacKenzie et al. 1989). Alternatively, the Barell matrix (Clark and Ahmad 2006) categorizes TBIs into Type I (most severe), II, or III (least severe) (see Table 4.6). A limitation of these approaches is that the ICD-9-CM code 959.01—"head injury unspecified"—is not included; thus, cases with this code are not automatically assigned a level of severity. Some researchers using ICDMAP-90 or the Barell matrix make the assumption that all 959.01 cases are in the mild range of AIS scores for TBI or represent Type III cases in the Barell matrix, or simply modify the matrix to include an "unspecified severity" category.

Representativeness of the data source is an important concern in TBI surveillance using administrative data sets. Representativeness means that either (a) the data source accurately captures *all* of the events of interest (e.g., the NVSS from the US National Center for Health Statistics) or (b) the data source *samples* the events, that is, TBIs, in a systematic manner so that the sample reflects the referent population (e.g., HDD from the US National Center for Health Statistics). Methods for detecting and assessing the magnitude of the bias are discussed elsewhere (Klaucke 1992). The use of hospital discharge data for TBI surveillance without including Emergency Department data can result in a lack of representativeness. For example, analysis of TBI surveillance data from Emergency Departments in South Carolina revealed that black females and the uninsured were less likely to be admitted to hospital, even after adjustment for TBI severity and preexisting conditions (Selassie et al. 2004).

Table 4.6 Barell matrix for TBI

ICD-9-CM codes	Description
Type 1 TBIs (most severe)	
800, 801, 803, 804 (0.03–0.05, 0.1–0.4, 0.53–0.55, 0.6–0.9)	Recorded evidence of intracranial injury or moderate/prolonged (≥1 h), LOC, or injuries to optic nerve pathways
850 (0.2–0.4)	
851–854	
950 (0.1–0.3)	
995.55	
Type 2 TBIs	
800, 801, 803, 804 (0.00, 0.02, 0.06, 0.09, 0.50, 0.52, 0.56, 0.59)	No recorded evidence of intracranial injury and LOC <1 h or of unknown duration or unspecified
850 (0.0, 0.1, 0.5, 0.9)	
Type 3 TBIs (least severe)	
800, 801, 803, 804 (0.01, 0.51)	No recorded evidence of intracranial injury and no LOC

Source: (Clark and Ahmad 2006)

Similarly, the validity of TBI surveillance data is also a concern and should be evaluated. Methods for evaluating TBI surveillance data sets are described in the CDC's Central Nervous System Injury Surveillance Data Submission Standards – 2002 (Marr and Coronado 2004). They include calculating the predictive value positive (PVP) and the sensitivity of the ICD codes used for surveillance. These measures require identification of a confirmatory diagnostic measure such as information from neurological evaluations that could be extracted from medical chart review or neuroimaging data, for example, computed tomography (CT). These methods are described in detail by Fletcher et al. (1988) and Fleiss et al. (2003).

Epidemiologic Measures in TBI Surveillance and Research

In this section, key measures used in previous studies are defined, selected measurement tools are described, and some relevant publications using these measures are summarized, focusing primarily on population-based studies.

Incidence and Related Measures

Incidence refers to the number of new TBI events that occur in a specific population or geographic region within a specified period of time. In population-based studies of TBI, incidence is typically calculated using data from administrative data sets. Incidence represents the number of people who *had* a TBI event whether or not they experienced related symptoms or problems after the acute phase of the injury. It is important to note that these numbers include people who experienced a TBI but may have fully recovered.

Faul et al. (2010) estimated the incidence of TBI in the USA by analyzing combined data from the National Center for Health Statistics (NCHS) regarding TBI (1) deaths (NVSS), (2) hospital discharges (NHDS), and (3) ED visits (NHAMCS) using the CDC case definition (Marr and Coronado 2004) (Table 4.3). Denominator data were obtained from the US Census. Using this approach, Faul et al. (2010) reported an estimated average annual incidence of TBI in the USA of 1.7 million per year (579.0 per 100,000 per year, age-adjusted to the 2000 US standard population).

An important limitation of the study is its failure to include non-fatal cases that only received medical attention in outpatient care settings. In addition, because the NHDS and NHAMCS data are based on hospitalizations and visits to EDs, not on individual persons, there may be some duplication of cases treated for the same injury; however, the estimated effects were small (Faul et al. 2010; Langlois et al. 2004) For details of the limitations of studies combining these three data sets, see the methods sections from these reports.

The incidence of TBI in the USA occurring in the year 2000 was calculated using different data sets (Finkelstein et al. 2006). As in Faul et al. (2010), they used NVSS for mortality. However, unlike the Faul et al. study, Finkelstein et al. estimated the incidence of nonfatal injuries that resulted in medical treatment without hospitalization or ED treatment from the 1999 Medical Expenditure Panel Survey (MEPS), a survey of the civilian, noninstitutionalized population (AHRQ 2011c). Because the MEPS sample size for nonfatal hospitalized and ED-treated injuries is small, they estimated the incidence of these injuries using the 2000 Healthcare Cost and Utilization Project-Nationwide Inpatient Sample (HCUP-NIS) for counts of hospitalized injuries. They estimated the incidence of injuries treated in the ED from the 2001 National Electronic Injury Surveillance System – All Injury Program (NEISS-AIP) (note: 2001 is the first complete year of NEISS data collection). For the denominator of the incidence rates, they used population counts from the 1999 MEPS. Using these data, they estimated that more than 1.3 million TBIs occurred in the USA in 2000 (486/100,000 per year).

Recurrent TBI, also known as repetitive TBI, refers to the occurrence of multiple incident TBI or concussion/mTBI events to the same person. Recurrent TBI, including concussion/mTBI, is important because it is associated with prolonged recovery (Guskiewicz et al. 2003) and increased risk of a catastrophic outcome such as second impact syndrome (CDC 1997). Previous head injury (including TBI) has also been shown to be a risk factor for subsequent head injury in children (Swaine et al. 2007) and for repeat concussion in collegiate athletes (Guskiewicz et al. 2003). In studies using administrative databases, recurrent TBI is ascertained by identifying other TBI event(s) for each case that are unrelated to the first (i.e., that are not readmissions or transfers) using unique patient identifiers.

In one of the first population-based studies of recurrent TBI, Annegers et al. (1980) reviewed medical record data for a 10-year period and reported that 7.1% of males and 3.0% of females experienced a second head injury. In a more recent study, Saunders et al. (2009) used statewide hospital discharge and ED records and reported that 7% of those hospitalized with a TBI had a least one recurrent TBI during the follow-up period. As mentioned above, studies that include only injury events resulting in medical attention underestimate the true incidence rate because they exclude less severe TBIs.

Trends in TBI rates, that is, increases or decreases in the incidence rates of TBI over time, are of interest because they may reflect important changes in health care practices or the effects of prevention. Using the National Hospital Discharge Survey, Thurman and Guerrero (1999) reported a 51% decline in US hospitalization for TBI, especially mild TBI, during the period from 1980 through 1995. Similar findings in Canada during the decade 1992–2002 have been reported by Colantonio et al. (2009). Bowman et al. (2008), using the HCUP Nationwide Inpatient Sample (NIS), reported that the estimated annual incidence rate of US pediatric hospitalizations associated with TBI decreased from 1991 to 2005.

Lifetime Prevalence of a History of TBI

Lifetime prevalence of TBI refers to the number or percent of individuals who have "ever" experienced a TBI whether or not they continue to have persistent symptoms or related disability. McKinlay et al. (2008) reported a lifetime prevalence of TBI of 30% in a birth cohort followed from

ages 0 through 25 years. Lifetime prevalence is an important indicator of the impact of TBI because preceding TBI has been shown in studies of birth cohorts to be associated with negative effects on psychosocial development (McKinlay et al. 2008) and later psychiatric morbidity (Timonen et al. 2002). It is also considered to be an important comorbid condition with implications for treatment, for example, in persons with substance abuse problems (Olson-Madden et al. 2010; Walker et al. 2007; Corrigan and Deutschle 2008).

Because prospective studies are not always possible, retrospective methods for determining a person's self-reported lifetime history of TBI have also been developed (Cantor et al. 2004; Corrigan and Bogner 2007). The Ohio State University Traumatic Brain Injury (TBI) Identification Method (OSU TBI-ID) is a standardized procedure for eliciting lifetime history of TBI via a structured interview (Corrigan and Bogner 2007). The instrument is based on CDC case definitions (Marr and Coronado 2004) (Table 4.3). The OSU TBI-ID was designed to use self- or proxy-reports to elicit summary indices reflecting TBIs occurring over a person's lifetime (see figure for the short version; a long version can be requested from the authors). Preliminary support for the reliability and validity of the measure has been published (Corrigan and Bogner 2007; Bogner and Corrigan 2009) (Fig. 4.1). According to the authors, the OSU TBI-ID can be adapted for specific populations and situations, primarily by modifying the "probe" questions (the first five questions in the short version). Because it is essential to spend time helping a respondent recall injuries and events that may have resulted in a TBI, the authors recommend that the OSU TBI-ID be administered via interview (telephone or face-to-face). Professionals with a background in TBI typically grasp the tool quickly, as do novice interviewers who have had some basic training about TBI. Using the OSU TBI-ID, Olson-Madden et al. (2010) found that 55% of a sample of veterans seeking outpatient substance abuse treatment had a history of previous TBI.

Outcomes

Long-Term Adverse Health Outcomes

Of particular concern after TBI are adverse outcomes that affect health and the ability to function in society. Unique population-based studies involving surveillance of longer-term TBI outcomes (up to 3 years postinjury) were supported by the CDC. In both the Colorado Traumatic Brain Injury Registry and Follow-up System (Brooks et al. 1997) and the South Carolina TBI Registry (Pickelsimer et al. 2006), representative samples of persons hospitalized with TBI were identified from statewide hospital discharge data surveillance systems and interviewed by telephone to obtain information about TBI-related outcomes including service needs (Corrigan et al. 2004; Pickelsimer et al. 2007), problems with psychosocial health (McCarthy et al. 2006), and alcohol use (Horner et al. 2005). Limitations of these studies included the exclusion of patients with less severe injuries seen in EDs, outpatient clinics, and those not receiving care.

Disability

Incidence of TBI-related disability refers to the number of people in a defined geographic region within a specified time period who have experienced a TBI and have long-term or lifelong disability. Methods for estimating the incidence of TBI-related disability involve the development and validation of a predictive model and application of the predictors from that model to a population-based data set. Selassie et al. (2008) developed a predictive model using logistic

Ohio State University TBI Identification Method—Short Form*
(Version 10/19/10-Lifetime: to be used when querying about lifetime history of TBI)

I am going to ask you about injuries to your head or neck that you may have had anytime in your life. *Interviewer instruction :* Record cause and any details provided spontaneously in the box at the bottom of the page. You do not need to ask further about loss of consciousness or other details during this step.

1. In your lifetime, have you ever been hospitalized or treated in an emergency room following an injury to your head or neck? Think about any childhood injuries you remember or were told about.
   ☐ Yes—Record cause in table below
   ☐ No
2. In your lifetime, have you ever injured your head or neck in a car accident or from crashing some other moving vehicle like a bicycle, motorcycle or ATV?
   ☐ Yes—Record cause in table below
   ☐ No
3. In your lifetime, have you ever injured your head or neck in a fall or from being hit by something (for example, falling from a bike or horse, rollerblading, falling on ice, being hit by a rock)? Have you ever injured your head or neck playingsports or on the playground?
   ☐ Yes—Record cause in table below
   ☐ No
4. In your lifetime, have you ever injured your head or neck in a fight, from being hit by someone, or from being shaken violently? Have you ever been shot in the head?
   ☐ Yes—Record cause in table below
   ☐ No
5. In your lifetime, have you ever been nearby when an explosion or a blast occurred? If you served in the military, think about any combat-or training-related incidents.
   ☐ Yes—Record cause in table below
   ☐ No
6. If all above are "no" then proceed to question 7. If answered "yes" to *any* of the questions above, ask the following for each injury: **Were you knocked out or did you lose consciousness (LOC)? If yes, how long? If no, were you dazed or did you have a gap in your memory from the injury? How old were you?**

Cause	Loss of consciousness (LOC)/knocked out				Dazed/Mem Gap		Age
	No LOC	< 30 min	30 min-24 hrs	> 24 hrs.	Yes	No	

<u>*If more injurieswith LOC*</u> : How many more?___Longest knocked out?___How many ≥ 30 mins.?___ Youngest age?___

7. Have you ever lost consciousness from a drug overdose or being choked? ____# overdose____# choked

<u>SCORING</u>

_____ **# TBI-LOC** (number of TBI's with loss of consciousness from #6)

_____ **# TBI-LOC ≥ 30** (number of TBI's with loss of consciousness ≥ 30 minutes from #6)

_____ **age at first TBI-LOC** (youngest age from #6)

Fig. 4.1 Ohio State University TBI Identification Method – Short Form*. (Version 10/19/10-Lifetime: to be used when querying about lifetime history of TBI)

_____ **TBI-LOC before age 15** (if youngest age from #6 < 15 then =1, if ≥ 15 then = 0)

_____ **Worst Injury** (1-5):

If responses to #1-5 are "no"classify as **1 "improbable TBI"**.

If in response to #6 reports never having LOC, being dazed or having memory lapses classify as **1 "improbable TBI"**.

If in response to #6 reports being dazed or having a memory lapse classify as **2 "possible TBI"**.

If in response to #6 loss of consciousness (LOC) does not exceed 30 minutes for any injury classify as **3 "mild TBI"**.

If in response to #6 LOC for any one injury is between 30 minutes and 24 hours classify as **4 "moderate TBI"**.

If in response to #6 LOC for any one injury exceeds 24 hours classify as **5 "severe TBI"**.

_____ **# anoxic injuries** (sum of incidents reported in #7)

*adapted with permission from the Ohio State University TBI Identification Method (Corrigan, J.D., Bogner, J.A. (2007). Initial reliability and validity of the OSU TBI Identification Method. *J Head Trauma Rehabil, 22*(6):318-329,

Fig. 4.1 (continued)

regression and data on post-TBI disability from a population-based sample of persons hospitalized with TBI from the South Carolina TBI Follow-up Registry (Pickelsimer et al. 2006). The regression coefficients were then applied to the 2003 HCUP NIS data to estimate the annual incidence of long-term disability in the USA following TBI hospitalization. In that study, an estimated 43.3% of hospitalized TBI survivors in the USA in 2003 experienced a TBI with related long-term disability (Selassie et al. 2008). These figures are likely underestimates because they are based on hospitalizations only and exclude TBIs treated in other settings or for which treatment was not sought.

Prevalence of TBI-related disability refers to the number of people in a defined geographic region, such as the USA, who have ever experienced a TBI *and* are living with symptoms or problems related to the TBI. This excludes people who had a TBI and recovered from it. Zaloshnja et al. (2008) estimated the number of people who experienced long-term disability from TBI each year in the past 70 years by applying estimates from a previous study of the incidence of TBI-related disability (Selassie et al. 2008) to data from the National Hospital Discharge Survey from 1979 to 2004. Then, after accounting for the mortality among TBI survivors, the authors estimated their life expectancy and calculated how many were expected to be alive in 2005. Applying this method, the estimated number of persons in the USA living with disability related to a TBI hospitalization was 3.2 million.

Estimates of the incidence and prevalence of TBI-related disability using these methods are limited by the omission of cases of less severe TBI. These studies used hospital discharge data only and thus do not include persons treated and released from Emergency Departments or who received no medical care. This is in part because data for TBI incidence and for mortality over

an extended period of time, for example, 70 years, are needed and are not readily available for persons treated in these health-care settings. Thus, available data only allow for meaningful estimates of the risk of disability after moderate and severe TBI. Another limitation is that there is no universally agreed-upon definition of TBI-related disability. The definition used by Selassie et al. (2008) was based on the findings from their study and included three domains: general health, mental and emotional health, and cognitive symptoms. Finally, it is important to consider the potential contribution of comorbid conditions to long-term disability. Selassie et al. (2008) found that preexisting comorbidity as assessed from the ICD-9-CM codes found in the hospital discharge records was strongly associated with disability, and thus, they adjusted for it in their model.

Late Mortality

Late mortality refers to TBI-related death occurring after the acute phase of recovery is over. In most previous population-based studies, late mortality has been assessed after discharge from acute care hospitalization (Selassie et al. 2005; Ventura et al. 2010). Information about late mortality is of interest because of the potential for serious injury such as TBI to adversely affect overall health and thus contribute to reduced life expectancy (Shavelle et al. 2006). Ventura et al. (2010) found that patients with TBI carried about 2.5 times the risk of death compared with the general population. As in the studies of disability described above, these late mortality findings are not generalizable to persons with less severe TBI who were not hospitalized, and the causal link between the TBI event and death can only be inferred.

Economic Cost

The economic burden of traumatic brain injury was investigated as part of a large and comprehensive study of the incidence and economic burden of injuries in the USA (Finkelstein et al. 2006). The authors combined several data sets to estimate the incidence of fatal and nonfatal injuries in the year 2000. They calculated unit medical and productivity costs, multiplied these costs by the corresponding incidence estimates, and reported the estimated lifetime costs of injuries occurring in 2000, with the estimated lifetime costs of TBI in their study totaling more than $60 billion. Orman et al. (2011) reported more detailed estimates of the lifetime costs of TBI. Unlike the previous estimates, the latter included lost quality of life. They found that, in 2009 dollars, the estimated total lifetime comprehensive costs of fatal, hospitalized, and nonhospitalized TBI among civilians that were medically treated in the year 2000 totaled more than $221 billion, including $14.6 billion for medical costs, $69.2 billion for work loss costs, and $137 billion for the value of lost quality of life. Notably, the nonhospitalized TBI category included cases presenting for ED, office-based, or hospital outpatient visits. These cost estimates are limited by the fact that that they do not adequately account for the costs of extended rehabilitation, services, and supports, such as informal caregiving, that are needed by those with long-term or lifelong TBI-related disability nor the value of lost quality of life or productivity losses for informal caregivers, including parents. Conversely, these estimates represent only TBIs associated with medical treatment. It is likely that the per person costs associated with most concussion/mTBIs are substantially less than the estimates resulting from this study methodology.

TBI Surveillance in Military Personnel and Veterans

Clinical Case Definition

The Department of Veterans Affairs/Department of Defense (VA/DoD 2009) TBI case definition was developed with input from both military and civilian TBI experts. Because it addresses issues specific to TBI among service members and veterans and differs slightly from previous definitions developed for civilian populations, the VA/DoD definition is summarized here:

- TBI is defined as a traumatically induced structural injury and/or physiological disruption of brain function as a result of an external force that is indicated by new onset of at least one of the following clinical signs, immediately following the event:
  - Any period of loss of or a decreased level of consciousness
  - Any loss of memory for events immediately before or after the injury
  - Any alteration in mental state at the time of the injury [confusion, disorientation, slowed thinking, etc., also known as alteration of consciousness (AOC)]
  - Neurological deficits (weakness, loss of balance, change in vision, praxis, paresis/plegia, sensory loss, aphasia, etc.) that may or may not be transient
  - Intracranial lesion
- External forces may include any of the following events: the head being struck by an object, the head striking an object, the brain undergoing an acceleration/deceleration movement without direct external trauma to the head, a foreign body penetrating the brain, forces generated from events such as a blast or explosion, or other force yet to be defined.

It is important to note that the above criteria define the "event" of a TBI. Not all individuals exposed to an external force will sustain a traumatic brain injury, but any person who has a history of such an event with manifestations of any of the above signs and symptoms, most often occurring immediately or within a short time after the event, can be said to have had a TBI. (VA/DoD 2009)

When evaluating the VA/DoD clinical case definition, it is important to keep in mind that diagnosing TBI among service members, especially those injured in combat, presents some unique challenges compared with the civilian setting. Although the diagnosis of moderate and severe TBI among service members is relatively straightforward even in a theater of war because the clinical signs and symptoms, abnormalities seen on neuroimaging, and the resulting functional deficits typically are readily apparent, the accurate identification of concussion/mild TBIs can be problematic. The reasons include the fact that (a) the often high pace of combat operations, referred to as OPTEMPO, and constraints on access to health care clinics in theater decrease the likelihood that an injured service member will be evaluated by a qualified provider soon after the injury event while concussion/mTBI signs and symptoms are observable; (b) there are limited diagnostic tools with known sensitivity and specificity that can be administered in the combat environment; (c) diagnoses based on self-report of exposure to an injury event are adversely affected by problems with recall, especially when the period of AOC or LOC is brief; and (d) concussion/mTBI symptoms overlap with those of other conditions such as acute stress reaction/post-traumatic stress disorder (Iverson et al. 2009; Hoge et al. 2008; Schneiderman et al. 2008; Marx et al. 2009; Pietrzak et al. 2009; Cooper et al. 2010; Kennedy et al. 2010; Polusny et al. 2011).

It is important to note that the case definition for concussion/mTBI summarized above was designed to be applied in the *acute* injury period. Thus, it lacks essential criteria for assessment of concussion/mTBI history, including the lack of specific symptoms, time course, and functional impairment. (Hoge et al. 2009). As a result, when it is used to assess concussion/mTBI weeks or months after the injury based on self-report, such as in some health screening programs, including the DoD's postdeployment health assessment (PDHA Form 2796) and postdeployment health reassessment (PDHRA Form 2900), subjective attribution of non-mTBI related symptoms to concussion/mTBI may occur (Hoge et al. 2009; Iverson et al. 2009). Misattribution of nonspecific symptoms, for example, headache, which may be due to other causes and not related to the injury event, can result in an overestimate of the true number of cases of concussion/mTBI. Estimates of the occurrence of TBI, including concussion/mTBI, based on results of screening have been reported (Hoge et al. 2008; Tanielian and Jaycox 2008; Terrio et al. 2009).

Enhanced surveillance for concussion/mTBI among deployed service members may be possible using the Blast Exposure and Concussion Incident Report (BECIR) (U.S. Medicine 2011). Under current Department of Defense guidelines for BECIR, every service member who is exposed to a potential concussion/mTBI, for example, who is within a specified distance of an explosion or blast, must be screened for common concussion/mTBI-related signs and symptoms, and the results must be recorded in the military's operational information system. Although originally designed to facilitate identification and clinical management of service members who sustain concussion/mTBI during deployment, the BECIR data may be useful in improving estimates of the incidence of combat-related concussion/mTBI.

DoD's Standard TBI Surveillance Case Definition for Administrative Health Care Data

A collaborative effort among experts from the Departments of Defense and Veterans Affairs and the civilian sector resulted in a standard case definition for surveillance of TBI among military personnel (AFHSC 2008, 2009, 2011a) (Table 4.7). The Armed Forces Health Surveillance Center (AFHSC) reports published prior to October 2008 used an older surveillance case definition (AFHSC 2008). Both the new and old DoD case definitions are similar, but not directly comparable, to that recommended by the CDC (Marr and Coronado 2004). Unlike the CDC definition, the DoD definition includes a range of V-codes and DoD-specific "extender codes" used within the DoD health system to capture information about self-reported history of injury (Tricare 2009). [These "extender codes" appear as an underscore followed by a number or letter directly after the V-code (see Table 4.7)]. Thus, the DoD definition allows inclusion of potential prevalent cases of TBI. An adapted version of the Barell Index for use with the DoD/VA standard surveillance case definition has been published (Wojcik et al. 2010a). Of note, the AFHSC definition is updated periodically, and a more recent version may currently be in use.

DoD Surveillance Methods

Two primary sources routinely report surveillance data for TBI among service members. The first source, the DoD TBI Numbers Web site, reports the numbers of service members with TBI diagnosed by a medical provider (DoD 2011). Cases are ascertained from electronic records of service members diagnosed anywhere in the world where the standard Department of Defense electronic health-care record, the Armed Forces Health Longitudinal Tracking Application (AHLTA), is used (DHIMS 2011). Second, population-based estimates of the numbers of service members and Veterans who sustain a TBI at any level of severity are routinely reported as a "deployment-related condition of special surveillance interest" by the AFHSC in their monthly publication, the *Medical Surveillance Monthly Report* (MSMR), available on line at the AFHSC Web site.

In a special report also in MSMR, the AFHSC published a detailed description of their surveillance methods and the challenges in calculating the incidence of TBI among service members using

Table 4.7 Department of Defense standard TBI surveillance case definition

The following ICD9 codes are included in the case definition[a, b]:
ICD-9-CM codes
310.2 (postconcussion syndrome)
800.0x–800.9x (fracture of vault of skull)
801.0x–801.9x (fracture of base of skull)
803.0x–803.9x (other and unqualified skull fractures)
804.0x–804.9x (multiple fractures involving skull or face with other bones)
850.x (concussion)
851.0x–851.9x (cerebral laceration and contusion)
852.0x–852.5x (subarachnoid, subdural, and extradural hemorrhage, following injury)
853.0x–853.1x (other and unspecified intracranial hemorrhage following injury)
854.0x–854.1x (intracranial injury of other and unspecified nature)
907.0 (late effect of intracranial injury *without* skull or facial fracture)
950.1–950.3 (injury to optic chiasm/pathways or visual cortex)
959.01 (head injury, unspecified)
(Personal history of TBI)
V15.52 (no extenders); V15.52_0 thru V15.52_9 ; V15.52_A thru V15.52_F (currently only codes in use)
V15.5_1 thru V15.5_9; V15.5_A thru V15.5_F
V15.59_1 thru V15.59_9; V15.59_A thru V15.59_F

Source: (Armed Forces Health Surveillance Center AFHSC 2011a, b)

[a]ICD-9-CM code 995.55 (shaken infant syndrome) is included in the standard DoD TBI case definition in an effort to be consistent with the CDC. This code is not used by AFHSC as it is not relevant to military surveillance objectives

[b]Case definition and ICD-9-CM codes are based on "TBI: Appendix F-G dated 5/1/10 and Appendix 7 dated 2/26/10: from *Military Health System Coding Guidance: Professional Services and Specialty Coding Guidelines* (Version 3.2) by the Unified Biostatistical Utility working group"

administrative health-care data (AFHSC 2009). Special considerations in reporting TBI surveillance data for service members include the classification of injury severity. Specifically, in addition to mild, moderate and severe, penetrating injuries are considered to have different prognostic significance and thus are categorized separately. With regard to external cause and setting, war-related TBIs are often associated with mechanisms not specified in routine civilian surveillance reports. These include explosions or blasts (Bell et al. 2009; Ling and Ecklund 2011) and high-caliber gunshot wounds (Bell et al. 2009). Whether the injury occurred in a battle vs. nonbattle setting is also of interest (AFHSC 2007; Wojcik et al. 2010b) but has typically been very difficult to differentiate reliably. External cause categories reported by AFHSC (2007) include falls, athletics/sports, assault, and accidental weapon-related. Although of considerable interest due to the ongoing conflicts in Iraq and Afghanistan, in one report, estimates of battle casualty-related TBIs accounted for a very small proportion of all TBI-related hospitalizations both prewar (0.3%) and during the wars (3.2%) (Orman et al. 2011).

Trends in TBI-related health-care encounters are also of interest. AFHSC (2011b) reported a trend toward increasing numbers of TBI-related ED visits among active duty US Armed Forces from 2001 to 2010, excluding visits for military personnel in civilian facilities and deployed settings. The potential effects of a wide range of changes since 2001, the onset of the conflicts in Afghanistan and Iraq, should be considered when interpreting these findings. Such changes include changes in TBI-related diagnostic procedures and guidelines, diagnostic coding practices, and awareness and concern among service members, commanders and supervisors, family members, and primary care and other health-care providers, which may have contributed to the higher rates (AFHSC 2011b).

Surveillance data for TBIs among service members based on health-care encounters have some limitations. As for civilians, the number of service members who receive medical care but for

whom the TBI is not diagnosed, or who sustain a TBI but do not seek care, is not known. Also, external cause information is incomplete and was missing/invalid for 25% of prewar TBI-related hospitalizations and 38% of those occurring postwar (AFHSC 2007). Finally, because denominator data, that is, the total number of deployed service members at risk of TBI, are not routinely available, deployment-specific TBI rates typically are not calculated but have been estimated in two studies (Ivins 2010; Wojcik et al. 2010b). This limits interpretation and comparison with data from other sources, such as from civilian data surveillance systems. Calculation of rates is needed to increase the usefulness of military TBI surveillance for guiding prevention efforts.

Combat-Related Trauma

As for TBI among civilians, trauma registries can be a useful source of data for studying serious traumatic brain injury among military personnel. Developed in 2004 at the United States Army Institute of Surgical Research (USAISR), The Joint Theater Trauma Registry (JTTR) is a standardized, retrospective data collection system for all echelons of combat casualty care that is similar in design to civilian trauma registries. The JTTR was the first organized effort by the US military to collect data on trauma occurring during an active military conflict (Glenn et al. 2008) and was designed to inform advances in medical care aimed at improving the outcome of soldiers wounded on the battlefield (Eastridge et al. 2006, 2009). Although not currently used for surveillance of combat-related TBI, the JTTR includes a range of data that would be useful for TBI surveillance, such as demographics, injury cause, mechanism and type, intentionality, ICD-9-CM diagnosis codes, external cause of injury codes (E codes), medical procedure codes (V-Codes), Abbreviated Injury Scale scores (AIS), Injury Severity Scores, and Glasgow Coma Scale scores. Because the JTTR includes detailed information about the medical care received, the data could be used for studies of trends in the types of TBI treatments used at various times and their association with changes in outcomes such as mortality. To date, few studies specifically focused on TBI have been conducted using JTTR data; however, DuBose et al. (2011) showed the potential for using JTTR to identify severe cases of combat-related TBI in their study of the relationship between neurosurgical interventions and outcomes.

Disability

For military personnel, disability is routinely defined as the inability to return to duty. Within the US Army, ability to return to duty is determined by the Army Physical Evaluation Board (PEB), an administrative body made up of medical personnel and Army officers who are responsible for determining if an ill or injured soldier is able to perform his or her job in the Army, that is, whether they are "fit for duty" (Cross et al. 2011). A condition that is judged to contribute to a soldier's inability to return to duty is referred to as an "unfitting condition." Studies conducted at the USAISR were among the first to quantify the disability associated with the wars in Afghanistan (OEF) and Iraq (OIF) by reviewing the PEB database. Cross et al. found that TBI was the eighth most frequent unfitting condition among soldiers injured between October 2001 and January 2005 identified from the JTTR. More recently, Patzkowski et al. (2011) queried the full PEB database and reported that for the first 3 months of 2009, TBI comprised 8% of the unfitting conditions for Army soldiers and ranked sixth, following back pain, osteoarthritis, PTSD, foot and ankle conditions, and psychiatric conditions. Similar studies for the other armed services would provide a more complete picture of the impact of TBI on return to duty for the entire US military force.

Future Directions in TBI Surveillance

Technological advancements are likely to lead to improvements in TBI diagnosis and related increases in the accuracy of case ascertainment for research and surveillance, especially for concussion/mTBI. Some examples include the following:

Neuroimaging. Accurate diagnosis of concussion/mTBI remains challenging due to the limitations of sign- and symptom-based diagnosis. However, recent studies suggest that structural abnormalities identified using more advanced neuroimaging techniques such as diffusion tensor imaging (DTI) might serve as quantitative biomarkers for concussion/mTBI (Niogi et al. 2008a, b; Wilde et al. 2008; Benzinger et al. 2009; MacDonald et al. 2011). Improvements in TBI diagnosis based on neuropathology will lead to an improved classification system for all levels of TBI severity not only for clinical research (Saatman et al. 2008) but also for epidemiologic studies.

Serum Biomarkers. Levels of certain biomarkers in blood measured after traumatic brain injury (TBI) may prove to be useful diagnostic and prognostic tools in addition to clinical indices for detection of blast-induced neurotrauma (Svetlov et al. 2009). If such biomarkers were found to be reliable for detecting concussion/mTBI, they would provide a more objective measure than symptom reporting. Promising candidates include S100B and GFAP (Vos et al. 2010).

Helmet Sensors. Electronic sensors have been placed in both football helmets (McCaffrey et al. 2007) and the helmets of service members (Army Technology 2011) to detect impacts from physical contact or blast/explosions. Data from these devices can be used as indicators of the impact to the brain of exposure to external forces and provide alerts to the possibility of sufficient impact to cause a concussion. Although not diagnostic, these sensors can be used to monitor the need to assess for symptoms of possible concussion. They can also be used to monitor the cumulative effect of multiple impacts that may be associated with recurrent concussions.

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